FIELD OF THE INVENTION

The present invention relates to diode side pumped high pulse energy lasers.

BACKGROUND OF THE INVENTION

Diode side pumped lasers are well known in the art, see US Pat. Nos. 5,778,020 and 5,774,488. For producing high power output from side-pumped solid state lasers, a number of diode bars have been tightly packed together to pump Nd:YAG lasing rod from symmetrically oriented multi-angles to produce high average power. When the laser crystal is not as durable as Nd:YAG, such as Nd:YLF, high pumping intensity along with high laser peak intensity and high average power often results in damage of the laser crystals. For example, current limitation for diode side pumped Q-switched pulsed Nd:YLF laser producing second harmonic wavelength beam is about 20mJ/pulse at 1kHz repetition rate. A higher pulse energy from Nd:YLF laser at fundamental or second harmonic wavelength at kHz repetition rates is desirable in many applications such as pumping short pulse amplifiers, dye lasers, high speed particle image velocimetry, laser welding and the like.

SUMMARY OF THE INVENTION

According to the invention, a high pulse energy, diode side pumped laser is provided. The laser has an optical cavity formed between a first and a second reflective surface. A lasing medium is located within the cavity along its optical axis. The lasing medium can be selected from a variety of lasing medium for example Nd:YAG, Nd:YLF or Nd:YVO_4 desirably a single lasing rod preferably a Nd:YLF lasing crystal desirably a Nd:YLF lasing rod. A plurality of diode bars are provided in optical communication with the lasing medium preferably a lasing rod. The diode bars supply electromagnetic radiation to the lasing rod. The diode bars are configured about the lasing rod so that electromagnetic radiation from the diode bars propagates through the lasing rod on a plurality of substantially nonintersecting paths. Since the lasing rod is side pumped, the substantially nonintersecting paths traverse the lasing rod substantially perpendicular to the direction of propagation of energy in the laser cavity.

Desirably the diode bars are located along the length of the lasing rod for delivering electromagnetic radiation to the lasing rod on a plurality of substantially nonintersecting paths. As a result, there is no substantial overlap of incoming energy from different diode bars at any point along the lasing rod.

In another aspect of the invention, a high pulse energy intracavity harmonic laser is provided. One or more harmonic crystals are desirably located within the laser cavity to generate a high pulse energy harmonic beam.

In still another aspect to the invention, a high pulse energy laser is provided having a lasing rod desirably a crystal rod having its optical axis through

the length of the rod. Six (6) or more diode bars are located along the lasing rod to deliver energy to the rod on substantially nonintersecting paths. Desirably the diodes are located around the periphery of the rod, and are preferably located symmetrically around the rod so the energy incidents on the rod from different sides.

It is an object of the invention to provide a high pulse energy laser which can be pumped at high power without damaging the lasing crystal.

It is an object of the invention to provide a high pulse energy harmonic laser having operational longevity.

It is an object of the invention to provide a high pulse energy Nd:YLF harmonic laser having operational longevity.

The preferred embodiment of the present invention is illustrated in the drawings and examples. However, it should be expressly, understood that the present invention should not be limited solely to the illustrative embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a partial perspective view of the laser according to the invention.

Fig 2 is a partial perspective view of the laser of Fig .1 showing the water cooling block.

Fig 3 is a partial perspective view of Fig 2 without the cooling block.

Fig.4 is a partial perspective view of Fig 3 without the reflective tube.

Fig.5 is a sectional view through 5-5 of Fig.3.

Fig.6 is schematic top view of the diode ,reflective tube and crystal.

Fig.7 is a schematic view of the pump beam path .

Fig.8 is a schematic view of a laser according to the invention.

Fig.9 is a schematic view of an alternative embodiment of laser according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

According to the invention, a high pulse energy, diode side pumped laser is provided. The laser has an optical cavity formed between a first and a second reflective surface preferably a first and second reflecting mirror. A lasing medium desirably a lasing rod is located within the cavity along its optical axis. The lasing medium is desirably a Nd:YAG, Nd:YLF, Nd:GdVO4 or Nd:YVO_4 lasing crystal rod preferably a Nd:YLF rod. The lasing rod can have a variety of cross sections desirably circular, rectangular or square. Typically the lasing rod is a cylindrical rod. Desirably the rod has a relatively long length desirably 70 mm or greater in

length preferably 90mm or greater in length. The lasing medium can be desirably a single lasing rod or optionally two or more lasing rods.

A plurality of diode bars are provided in optical communication with the lasing medium preferably a Nd:YLF lasing rod. The diode bars are oriented about the lasing rod to supply electromagnetic radiation through the lasing rod on a plurality of substantially nonintersecting paths. Since the lasing rod is side pumped, the substantially nonintersecting paths traverse the lasing rod substantially perpendicular to the direction of propagation of energy in the laser cavity. As a result, there is no substantial overlap of incoming energy at any give point along the lasing rod. Desirably any overlap is kept to a minimum desirably 20% or less preferably 10% or less.

When two or more lasing rods are employed, desirably a plurality of diode bars are provided in optical communication with each lasing rod. Electromagnetic radiation from the diode bars propagates through each lasing rod on a plurality of substantially nonintersecting paths. Since each lasing rod is side pumped, the substantially nonintersecting paths traverse each lasing rod substantially perpendicular to the direction of propagation of energy in the laser cavity. As a result, there is no substantial overlap of incoming energy at any point along any lasing rod. For example when there are three lasing rods, multiple diode bars would be in optical communication with each lasing rod.

In another aspect of the invention, a high pulse energy intracavity harmonic laser is provided. One or more harmonic crystals are located within the

laser cavity to generate a high pulse energy harmonic beam. Preferably a second harmonic nonlinear crystal is located within the cavity to produce a second harmonic beam. Optionally second and third harmonic crystals or second, third, and fourth harmonic crystals are located within the cavity to produce third or fourth harmonic beams.

In still another aspect to the invention, a high pulse energy laser is provided having one or more lasing rods desirably a single crystal rod having its optical axis through the length of the rod. Six (6) or more diode bars preferably nine (9) or more desirably nine (9) to eighteen (18) diode bars are linearly spaced along each lasing rod preferably a Nd:YLF lasing rod to deliver energy to the rod at linearly spaced points along the laser's optical axis. Desirably the diodes are oriented around the periphery of the rod, desirably symmetrically located around the rod so that the electromagnetic radiation from the diodes bars propagates through the lasing rod on a plurality of substantially nonintersecting paths.

Referring to the Figures, a best seen in Fig. 1, 8 and 9, a laser cavity is formed between mirrors 10 and 12 which are both highly reflective for fundamental beam. One or more lasing rod preferably a single cylindrical Nd:YLF lasing rod 40 is located in the cavity. Desirably the optical axis extends through the entire length of the crystal rod 40. Diode bars 44 preferably banks 42 of diode bars are provided to side pump rod 40.

As best seen in Figs.1 to 7, a plurality of diodes bars 44 are provided along the length of the lasing rod 40 for delivering electromagnetic radiation to the

lasing rod at a plurality of incident points along the optical axis. Desirably, six (6) or more diode bars preferably nine (9) or more, desirably nine (9) to eighteen (18) diode bars are linearly spaced along a lasing rod 40. Desirably as shown in Figs. 1 to 4 nine (9) diode bars 44 in three (3) banks 42 are provided. The diode bars 44 are located so that the energy propagating from diode bar outlets 46 propagates through the lasing rod 40 on a plurality of substantially nonintersecting paths as shown in Fig. 2, 3, 4 and Fig. 6. Preferably the diode bars 44 are provided in banks 42 of 2 or more bars desirably 3 to 6 or more diode bars to a bank preferably 2 to 4 diode bars to a bank. Desirably the diodes bars 44 preferably banks 42 of diode bars are symmetrically located around the lasing rod preferably Nd:YLF rod 40 while preferably being linearly spaced from one another along the optical axis. As a result, there is no substantial overlap of incoming energy along the lasing rod 40. A reflective tube 52 desirably a quartz tube having a reflective coating 50 receive lasing rod 40. The reflective coating 52 is desirably a gold, silver or dielectric reflective coating preferably a gold reflective coating. Slits 56 are provided in coating 50 facing outlets 46 of the banks 42 of diode bars. Desirably the slits 56 are antireflction coated to reduce undesired reflection of the pump beams. As best seen in Fig.5, a space 48 is preferably provided between reflection tube 52 and lasing rod 40 which acts as a channel for cooling water for the rod 40. Rod holders 54 located at both ends of the lasing rod 40 hold it in place. Tube holders 55 hold reflective tube 52 in position.

Preferably the lasing rod 40 is 70mm or greater desirably 90mm or greater preferably from 90 to 120 mm in length. Diodes bars are located along the length of the rod, desirably 6 to 18 or more diode bars preferably 9 to 15 diode bars desirably symmetrically located around the rod so that the electromagnetic radiation from the diodes bars propagates through the lasing rod on a plurality of substantially nonintersecting paths. Preferable the diodes bars 44 are linearly spaced apart along the optical axis. *As best seen in Figs. 4 and 6 , there can be a* small amount of overlap of energy paths of adjacent diode bars. Path 70 has a path side wall 62 that intersects path 72 side wall 64 to provide an insubstantial overlap desirably 20% or less preferably 10% or less .

In another aspect of the invention, as best shown in Figs. 8 and 9 , a high pulse energy intracavity harmonic laser is provided. A Q-switch is provided within the cavity formed between mirrors 10 and 12. A lasing rod 40 is provided in the cavity. Optionally as shown Fig. 9, two (2) or more lasing crystals 60 and 61 can be provided. Desirably as shown in Fig. 8, a folding mirror 14 is provided in optical communication with lasing rod 40. One or more harmonic crystals are located within the laser cavity to generate a high pulse energy harmonic beam. Preferably a second harmonic nonlinear crystal SHG as shown in Fig. 8 is located within the cavity to produce a second harmonic beam. Optionally as shown in Fig. 9 a second harmonic generator SHG and third harmonic generator or second SHG, third THG, and fourth harmonic FHG generators preferably nonlinear crystals are located within the cavity to produce third or fourth harmonic beams. Folding mirror 14 is highly reflective for fundamental beam and highly

transmissive for harmonic beam that is for second, third or fourth harmonic depending on the desired harmonic output. Desirably, the diodes and lasing rod are water cooled. Water is provided to base 56 from a convenient source. Conduits are provided in the base 58 to provide water to cool the diode bars 44 and the lasing rod 40 . For example each bank of diodes can have a separate stream of cooling water. Within each bank, the diode bars can be serially cooled from a single stream. A separate stream can be provided to directly cool the crystal by introducing water into the hollow reflecting tube 52 through channel 48.

In operation, the diode bars 44 in diode banks 42 are activated to produce pumping energy for rod 40. The electromagnetic radiation from the diodes bars 44 propagates through the lasing rod on a plurality of substantially nonintersecting paths. Preferable the diodes bars 44 are linearly spaced apart. The energy from the diode bars passes through the anti-reflection coated slits 56 to pump the laser rod. Electromagnetic radiation left from the first pass through the laser rod is reflected back by reflective coating surface 50 of reflecting tube 52 to further pump rod 40. As best seen in Fig. 7, the energy that is not absorbed by rod 40 is reflected by reflective tube 52 back through the rod 40 for further absorption. Since the energy from the diode bars 44 does not substantially overlap, the pump intensity along the laser rod is substantially uniformly distributed. The total amount of available pumping power is distributed along a longer laser rod which results reducing stress placed on the rod 40. As a result,

the Nd:YLF rods can be pumped at a greater energy level to produce a higher power output without damaging the crystal.

The foregoing is considered as illustrative only to the principles of the invention. Further, since numerous changes and modification will occur to those skilled in the art, it is not desired to limit the invention to the exact construction and operation shown and described above, and accordingly, all suitable modifications and equivalents may be resorted to, falling within the scope of the invention.